

Too big to Innovate? Scale (dis)economies and the competition-innovation relationship in U.S. banking

Citation for published version (APA):

Bos, J. W. B., Lamoen van, R., & Eonomidou, C. (2010). *Too big to Innovate? Scale (dis)economies and the competition-innovation relationship in U.S. banking*. METEOR, Maastricht University School of Business and Economics. METEOR Research Memorandum No. 054
<https://doi.org/10.26481/umamet.2010054>

Document status and date:

Published: 01/01/2010

DOI:

[10.26481/umamet.2010054](https://doi.org/10.26481/umamet.2010054)

Document Version:

Publisher's PDF, also known as Version of record

Please check the document version of this publication:

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Download date: 06 May. 2023

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RM/10/054

METEOR

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Too Big to Innovate? Scale (dis)economies and the Competition-Innovation Relationship in U.S. Banking[☆]

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Abstract

This paper examines whether large U.S. banks have become 'too big to innovate'. We extend the theoretical work of Aghion et al. (2005b) by relaxing their assumption that unit costs are independent from output levels in order to investigate the effect of scale (dis)economies on the competition-innovation nexus. With our model we can derive conditions under which the innovation behavior of firms with scale diseconomies becomes more or less responsive to competitive changes. Our empirical results show that decreases in the level of competition lead to very large drops in innovation. Large banks, already operating beyond the minimum efficient scale, have indeed become 'too big to innovate'.

Keywords: competition, innovation, scale economies, frontier, technology gap

JEL: D21, G21, L10, O30

1. Introduction

During the last two decades, the banking sector has changed profoundly. Globalization, advances in information technology, mergers and acquisitions and consolidation have reshaped the banking sector as the number of banks in the U.S. declined by nearly fifty percent (Berger et al., 1995, 1999). At the same time, the average size of banks has increased substantially, as banks with assets totaling more than ten billion dollars increased their share of banking industry assets from thirty percent to over seventy percent (Rhoades, 2000). Similar consolidation trends have occurred in the European Union, Japan, and other countries (Carletti et al., 2007).

Increased consolidation raises concerns, as more concentrated markets are generally believed to facilitate collusion (Berger et al., 2004).¹ But consolidation may have other negative consequences as well. If large banks operate with increasing average costs, this affects their innovation incentives, as future profits

[☆]We thank Martijn Drees, Iftekar Hassan, Clemens Kool, Philip Molyneux, participants at the 2009 European Workshop on Efficiency and Productivity Analysis in Pisa, Italy, the 2010 EURO Workshop on Efficiency and Productivity Analysis in Chania, Crete, and seminar participants at Utrecht School of Economics for helpful comments. The usual disclaimer applies.

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¹The relationship between market structure and competition has attracted considerable attention in the literature. However, the results are mixed. For example, Berger and Hannan (1989) find a robust positive relationship between profitability and market concentration in retail banking markets in the late 1980s. In contrast, Cole et al. (2004) report no evidence that differences in loan approval procedures of large banks versus small banks had a negative effect on pricing and volume in the market for small business lending. In tests of how competition in local banking markets affects the market structure of non-financial sectors, Cetorelli and Strahan (2006) showed that potential entrants faced greater difficulty gaining access to credit in concentrated markets than in more competitive markets.

from innovations are dampened by a further increase in average costs. In turn, a less innovative banking sector may raise the costs of financial intermediation and have negative effects on economic growth.²

Despite the widespread recognition of the rapid and broad proliferation of financial innovation and the relative abundance of innovation studies for other sectors of the economy (manufacturing, agriculture), there is a relative dearth of empirical studies on financial innovation.³ Even less is known about the relationship between competition and innovation in banking.

Nonetheless, the competition-innovation nexus itself has recently received a boost by some important advances. Whereas the seminal work by Schumpeter (1942) posits that competition discourages innovation by diminishing monopoly rents that result from innovation (the so-called 'Schumpeterian effect'), recent work by Aghion et al. (2001) argues that competition may foster innovation as firms attempt to escape competition (the so-called 'escape competition effect') by engaging in innovative activities.⁴ In an attempt to reconcile these theories and mixed empirical evidence, Aghion et al. (2005b) have proposed a theoretical model that establishes an inverted-U relationship between competition and innovation, wherein an escape competition effect initially dominates until competition reaches a sufficient level such that the Schumpeterian effect prevails thereafter.⁵ Their empirical evidence for manufacturing firms in the U.K. tends to support the hypothesis of an inverted-U pattern. Scherer (1967), Levin and Mowrey (1985) and Hashmi (2007) also find evidence of an inverted-U relationship between competition and innovation. Bos et al. (2009) extend the previous literature from manufacturing to financial services and find an inverted-U relationship between competition and innovation in U.S. banking.

An important limitation of the existing literature is the fact that it has ignored the effect of firm size on the competition-innovation relationship, relying instead on the premise that unit costs are independent from output levels (Aghion et al., 2005b). However, for many industries this assumption may not hold. An important example is the common finding of U-shaped average cost curves in the U.S. banking industry (Berger et al., 1999; Vives, 2001). In the presence of a Minimum Efficient Scale (MES), bank size may play an important role in the competition-innovation relationship, as some banks may become 'too big to innovate': for these banks, the growth opportunities are limited compared to smaller firms below the MES or may even come at a penalty of higher average costs.⁶ Consequently, the existence of scale diseconomies for these firms constitutes an additional reason for concern in a consolidating market, since these large firms may react to any further decreases in competition with strong decreases in their innovation effort, as was the case during the recent global financial crisis.⁷

The aim of this paper is to examine this relationship between scale economies, competition and innovation in order to find out whether there is such a thing as being 'too big to innovate' in the U.S. banking sector in the period 1984-2004, a period of substantial consolidation. To our knowledge, this paper constitutes the first theoretical and empirical investigation of the impact of scale (dis)economies on the competition-innovation nexus.

The paper contributes to the literature in two distinct ways. The first contribution consists of an important extension of the theoretical model of Aghion et al. (2005b) to account for scale economies in studying

²The importance of financial services for economic growth has been long documented in the literature. Theoretical and empirical advances relate financial development to an improved allocation of capital, better risk sharing and possibly a higher savings rate (King and Levine, 1993; Pagano, 1993; Levine, 2004; Levine et al., 2000).

³For instance, Berger (2003) presents an overview of technical change in the US banking industry (e.g., automatic teller machines, electronic payments services, internet websites, information exchanges, computer-based credit risk scoring models, etc.) and infers that "competition may currently or in the near future force banks to adopt technology just to keep existing customers" (p. 149). He also observes that larger banks have been earlier adopters of new technologies than smaller banks. See also Mishkin and Strahan (1999), DeYoung and Hunter (2001), Berger and DeYoung (2006) and Jones and Critchfield (2005).

⁴See literature reviews by Kamien and Schwartz (1982) and Symeonidis (1996).

⁵Their model is also able to explain positive or negative effects of competition on innovation.

⁶Of course, for firms that operate below the MES, cost scale economies represent a bonus from innovation. These firms experience more growth opportunities compared to firms with scale diseconomies since firm growth results in lower average costs and increases in their profits. As a result, the existence of scale economies may constitute a key driver of consolidation.

⁷The large cuts on Information Communications Technology (ICT) spending by large banks during the recent financial crisis points in this direction. According to the Celent (2009) financial report, the growth in the information technology spending by the North American banks in 2009 is modest (1.7%), compared to past years' spending. The drop is even more dramatic for large European banks, who decreased ICT spending by 5.8% in 2009.

the competition-innovation relationship. In the original model, all firms operate at identical, fixed average costs. As a result, innovation is independent of firm size and scale economies. We augment the structure of the cost function to allow for U-shaped average costs, and modify the empirical model of Aghion et al. (2005b) to distinguish between firms that operate below and above the MES.

The second contribution of this paper lies in the application of a novel innovation measure in the context of this study. Instead of using traditional innovation measures based on outputs or inputs (e.g., patents and R&D spending, which are mostly relevant to manufacturing), we focus on banks' ability to minimize costs through process innovations. Following early work by Hayami and Ruttan (1970), Mundlak and Hellinghausen (1982) and Lau and Yotopoulos (1989), we estimate and envelope annual minimum cost frontiers to create a meta frontier, which represents the best (potential) available technology. The distance to the latter constitutes each bank's technology gap, which is reduced if the bank manages to innovate. Our proposed measure has three advantages. First, it enables us to examine the innovation behavior of firms in a sector where traditional measures such as patents, R&D expenditures, number of scientists and engineers are less applicable and suffer from several limitations (Kamien and Schwartz, 1982; Acs and Audretsch, 1987; Geroski, 1990; Griliches, 1990).⁸ Second, our measure closely aligns with the model of Aghion et al. (2005b) as each innovation leads to lower production costs (process innovation) and laggard firms can catch up with leaders by inventing and imitating. Thirdly, contrary to the past literature that focuses on one type of technology (e.g. adoption of ATMs), our proposed measure captures all types of invention that lead eventually to cost reductions.⁹

The theoretical implications of our model and application of our methodology are tested on a rich data set of U.S. banks. Our analysis is organized around the following questions: (i) How have scale economies and competition developed in the consolidating U.S. banking market? and (ii) How has the increase in bank size affected the relationship between competition and innovation in U.S. banking: have large U.S. banks become too big to innovate?

Our results are easy to summarize. We find evidence that many banks in the U.S. experienced scale diseconomies during the consolidation period. In the same period, the upward trend in the average price cost margins implies that the degree of competition in the banking sector has declined. Furthermore, our results show that banks that operate above the MES have indeed become 'too big to innovate': these banks' process innovation is more sensitive to changes in competition, confirming fears that further decreases in competition and more consolidation pose a serious threat to innovation in U.S. banking.

Our findings have important implications for competition policy. Although the current crisis has revived fears of banks having become too big to fail (Melvin and Taylor, 2009), the consolidation trend in U.S. banking continues. To some extent, charter values in banking may increase financial stability. But our results make clear that any further decreases in competition come at a high price: innovation is expected to fall sharply due to the strong reaction of large banks that have become 'too big to innovate'.

The remainder of the paper is organized as follows. Section 2 describes how we extend the theoretical model of Aghion et al. (2005b) and its application to the banking sector. Section 3 discusses the data and methodology. Empirical results are presented in Section 4. Section 5 concludes.

2. Theoretical Framework

This section presents our model. The model is based on the theoretical contribution of Aghion et al. (2001) and Aghion et al. (2005b), who develop a growth model to investigate the relationship between competition and innovation. We follow Aghion et al. (2001) and Aghion et al. (2005b), unless it is stated otherwise. We start by explaining the set-up of the model, introducing a U-shaped average cost function. Next, we proceed with the derivation of equilibrium profits and the Schumpeterian and escape competition

⁸For example, not all innovations are patented and R&D expenditures may systematically understate the research activity of small firms. Frame and White (2004) argue that patents for financial products and services are not common, financial services firms rarely have R&D budgets and rarely employ scientists and engineers. See Frame and White (2004) for a discussion on the data restrictions in financial services concerning innovation measures.

⁹See, for instance, the work of Hannan and McDowell (1984).

effect. Finally, we describe the effect of a U-shaped average cost function on the competition-innovation relationship.

2.1. Basic model with a U-shaped average cost function

In this subsection, we introduce the key elements of the model with a U-shaped average cost curve. We assume that a sector faces identical consumers with a constant inter-temporal discount rate, r , and a log-utility function that can be described by:

$$u(y_t) = \ln y_t, \quad (1)$$

where y_t denotes the consumption good of the sector.

The sector consists of a continuum of intermediate sectors that produce $y_t = \int_0^1 \ln x_{jt} d_j$, where x_{jt} is an aggregate of two intermediate goods produced by firm A and B (duopoly) in the intermediate sector j . The total production of each intermediate sector is $x_j = \sqrt[\alpha]{x_{Aj}^\alpha + x_{Bj}^\alpha}$, where α is the degree of substitutability between products.¹⁰

The innovation rates of a technological leader, laggard firms and neck-and-neck firms (that are at technological par with one another) are denoted n_1 , n_{-1} and n_0 , respectively. The laggard bank moves ahead with the hazard rate $n + h$ if it puts effort into R&D, where h is a help factor that represents R&D spillovers or the ability to copy the technology of a leader. The R&D cost function $\psi(n) = n^2/2$ is expressed in units of labor n . By assumption, technological advances occur through step-by-step innovations instead of leapfrogging and the maximum technological gap, m , in a sector is assumed to be one ($m = 1$) since laggard firms can adopt the leader's previous technology.¹¹ Therefore, $n_1 = 0$, as a firm that is already a leader has no incentive to innovate further. Firms (banks, in our case) only use labor as an input at the (exogenous) normalized wage rate $w = 1$ and it is assumed that the production function exhibits constant-returns.

A key assumption of the Aghion et al. (2005b) model is that unit costs are independent from the quantity produced. In particular, the unit cost function in their model is γ^{-k_i} , where γ represents the size of an innovation (and is assumed to be larger than one) and k is the technological level. Hence, innovations lower the unit cost due to a decrease in the required units of labor per unit of output. However, models based on the assumption that unit costs are independent from output levels are less appropriate in sectors where average costs are not constant and may thereby affect the competition-innovation relationship. In the model of Aghion et al. (2005b), for a given level of competition, innovation incentives depend on the incremental profits from innovation.¹² To see how non-constant average costs affect this innovation incentive, consider the U-shaped average cost curves that exist in many sectors, such as the banking sector, where the MES is less than infinity. The existence of scale (dis)economies may influence the innovation incentives by affecting the incremental profits from innovation. For example, scale diseconomies lower current profits and can hamper the growth opportunities of firms and their future profits. However, in the model of Aghion et al. (2005b) firms cannot exhibit scale economies and consequently the current firm size and firms' growth potential cannot affect the innovation behavior of firms (through the relationship between scale economies and incremental profits from innovation).

We depart from Aghion et al. (2005b) and allow for U-shaped average costs. We propose the following total cost function:

$$TC_i = F + w\gamma^{-k_i} x_i^\delta, \quad (2)$$

where F are fixed costs, w is the wage rate (assumed to be equal to 1), δ is a non-negative integer and x_i is the output of firm i . The cost function in Aghion et al. (2005b) is a special case of equation (2), where $\delta = 1$

¹⁰The logarithmic utility function in equation (1) implies that in equilibrium individuals spend the same amount on each aggregate of intermediate goods x_j .

¹¹It is impossible for laggard firms to surpass a technological leader by means of an innovation without first drawing even with this leader. See Aghion et al. (1997) for several appealing features of a model of step-by-step innovation compared to the Schumpeterian leapfrogging models.

¹²The incremental profit from innovation is the difference between post- and pre-innovation profits.

and $F = 0$. Since γ^{-k_i} represents the amount of labor needed to produce one output, $w\gamma^{-k_i}$ represents the labor expenses per unit of output. The average cost function is:

$$AVC_i = \frac{F}{x_i} + \gamma^{-k_i} x_i^{\delta-1}. \quad (3)$$

The domain of this average cost function is the open interval $x \in (0, \infty)$. Differentiating the function with respect to x_i and setting the derivative equal to zero, yields the output x_i^* that is associated with the Minimum Efficient Scale (MES) of production:

$$x_i^* = \sqrt[\delta]{\frac{F}{(\delta-1)\gamma^{-k_i}}}. \quad (4)$$

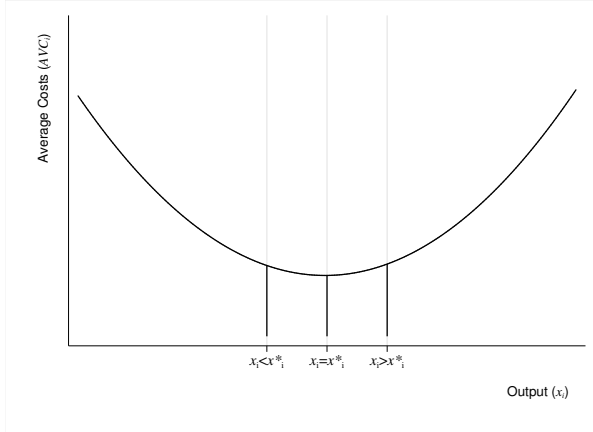
Figure 1a illustrates the result, with firms producing below ($x_i < x_i^*$), at ($x_i = x_i^*$) or above ($x_i > x_i^*$) the MES. The optimal scale size of production depends on the size of an innovation and the technological level of a bank. Defining the unit labor requirement as $\Gamma = \gamma^{-k_i}$ and differentiating the MES with respect to the unit labor requirement shows that lower levels of unit labor requirements lead to a higher optimal scale:

$$\frac{\partial x_i^*}{\partial \Gamma} = \frac{1}{\delta} \left(\frac{F}{(\delta-1)\gamma^{-k_i}} \right)^{\frac{1-\delta}{\delta}} \left(\frac{-F(\delta-1)}{((\delta-1)\gamma^{-k_i})^2} \right) < 0. \quad (5)$$

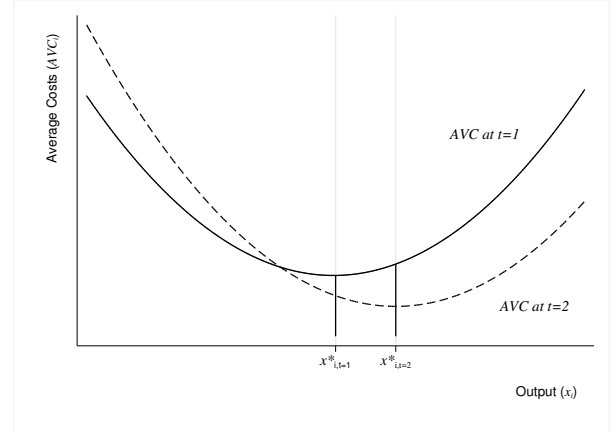
Figure 1b illustrates this result, with the solid line depicting the average cost curve based on the current technology in period $t = 1$. After an innovation, the technology of the firm improves and the MES increases in period $t = 2$. Thus firms can operate at a higher optimal scale after improvements in their technology.

Figure 1: U-shaped average costs, optimal size and innovation

(a) Operating above, at and below the minimum efficient scale (MES)



(b) Average costs for different values of the unit labor requirement



2.2. Equilibrium profits and the escape competition and Schumpeterian effect

Aghion et al. (2001) show that the equilibrium profit of each firm depends only on its relative costs, z_i . Using the cost structure in equation (2), the relative unit costs (z_i) of a firm become:

$$z_i = \frac{MC_i}{MC_{-i}} = \frac{\delta \gamma^{-k_i} x_i^{\delta-1}}{\delta \gamma^{-k_{-i}} x_{-i}^{\delta-1}} = \frac{x_i^{\delta-1}}{x_{-i}^{\delta-1}} \gamma^{-m}, \quad (6)$$

where MC_i and MC_{-i} are the marginal costs of firms i and (the other firm) $-i$, respectively and m is the technological gap (lead or lag) of a firm.¹³ If $\delta = 1$, we obtain the relative cost as in the model of Aghion et al. (2001), namely γ^{-m} .¹⁴ Aghion et al. (2001) show that each firm's equilibrium profit function is:

$$\pi_i = \frac{\lambda(z, \alpha)(1 - \alpha)}{1 - \alpha\lambda(z, \alpha)}, \quad (7)$$

where λ is firm's revenue.

We follow Aghion et al. (2005b) and model the degree of product market competition by the ability of two neck-and-neck firms to collude.¹⁵ Firms are assumed to engage in Bertrand competition. The profits of laggards, neck-and-neck firms and technological leaders are π_{-1} , π_0 and π_1 , respectively. Collusion is assumed to only be possible when firms have equal unit costs. The profits of firms with equal costs are defined as:

$$\pi_0 = \epsilon \pi_T, \quad \epsilon \in \left[\frac{\pi_{0nc}}{\pi_T}, \frac{1}{2} \right], \quad (8)$$

where ϵ represents the share of the total (perfectly) collusive profits π_T , and π_{0nc} represents the profits when both neck-and-neck firms do not collude. The share of the maximum total collusive profits ϵ is exogenously determined in the model and defined on a closed interval, where π_{0nc}/π_T is the minimum share value that indicates no collusion and the maximum share value $1/2$ indicates an equal division of the total (perfectly) collusive profits. From equation (8), we learn that the profits of neck-and-neck firms π_0 can be used as a measure of competition. Ceteris paribus, more collusion leads to higher profits and less collusion to lower profits.

As in Aghion et al. (2005a), the following equilibrium research intensities, n_0 and n_{-1} , are obtained from the Bellman equations:

$$n_0 = -h + \sqrt{h^2 + 2(\pi_1 - \pi_0)}, \quad (9)$$

$$n_{-1} = -(h + n_0) + \sqrt{(h + n_0)^2 + 2(\pi_0 - \pi_{-1}) + n_0^2}. \quad (10)$$

The research intensities depend only on the current technological state. Furthermore, the discount rate is assumed to be zero ($r = 0$). These research intensities can be used to examine how the escape competition and Schumpeterian effect are affected if firms experience scale economies or scale diseconomies. The escape competition and Schumpeterian effect are obtained by differentiating the research intensities with respect to the measure of competition π_0 . Equation (11) shows the escape competition effect:

$$\frac{\partial n_0}{\partial \pi_0} = -\frac{1}{\sqrt{h^2 + 2(\pi_1 - \pi_0)}} < 0. \quad (11)$$

Equation (11) illustrates that competition, reflected by a lower π_0 , has a *positive* effect on the innovation incentives of neck-and-neck firms. More competition increases incremental profits from innovating by lowering the current profits. Equation (12) represents the Schumpeterian effect:

$$\frac{\partial n_{-1}}{\partial \pi_0} = -\frac{\partial n_0}{\partial \pi_0} + \frac{((h + 2n_0)\frac{\partial n_0}{\partial \pi_0} + 1)}{\sqrt{(h + n_0)^2 + 2(\pi_0 - \pi_{-1}) + n_0^2}} > 0. \quad (12)$$

¹³Firms are assumed to be homogeneous with respect to the δ parameter.

¹⁴Profits also depend on the degree of substitutability between the two products of the two intermediate sectors. Since the relative marginal cost function is not defined if x_{-i} is zero, we assume that the degree of substitutability is not perfect and hence firms always produce.

¹⁵Aghion et al. (2001) use the substitutability between products parameter α as a competition measure.

It shows that competition has a *negative* effect on the innovation incentives of laggard firms. Increases in competition reduce the rents that these laggard firms can earn after they innovate and hence lead to a decrease in incremental profits from innovating. This decrease in their incremental profit lowers their innovation incentives.

Aghion et al. (2005b) show that the inverted-U relationship between competition and innovation depends on the escape competition effect and the Schumpeterian effect. Below the optimal level of competition that enhances innovation, the escape competition effect dominates and beyond the optimal level of competition the Schumpeterian effect dominates. In the next section, we extend the model of Aghion et al. (2005b) to examine the effect of scale (dis)economies on the escape competition effect, the Schumpeterian effect and the competition-innovation relationship.

2.3. The effect of a U-shaped average cost function on the competition-innovation relationship

Producing below or beyond the MES may lead to differences between the incremental profits from innovating. Post innovation profits are affected by scale economies in two ways. First, after innovating firms receive a bonus (pay a penalty) since, operating below (above) MES, the innovation results in output increases that are accompanied by less (more) than proportional increases in costs. Second, *differences* in scale economies can have an indirect effect, by changing the likelihood of collusion.¹⁶ Scale diseconomies make undercutting a less profitable strategy in the present due to increases in average costs. However, scale diseconomies may also foster competitive behavior by reducing the capacity to retaliate against competitive pricing. As a result, it is as yet unclear how a U-shaped average cost curve affects the ability to collude (Tirole, 1988).

However, we can investigate the direct effect of scale economies. To start with, the relationship between scale economies and the escape competition can be examined by differentiating equation (11) with respect to the incremental profits $\chi = \pi_1 - \pi_0$:

$$\frac{\partial^2 n_0}{\partial \pi_0 \partial \chi} = \frac{1}{(h^2 + 2\chi)^{3/2}} > 0. \quad (13)$$

Equation (13) is used to examine the magnitude of the escape competition effect if incremental profits (χ) of neck-and-neck firms change. Higher incremental profits result in a lower escape competition effect. Neck-and-neck firms with scale economies have higher post-innovation rents π_1 if their average costs decrease due to firm growth. Large neck-and-neck firms with scale diseconomies have lower incremental profits χ if they expect lower post-innovation rents π_1 and/or higher current profits π_0 due to collusive behavior. Consequently, these large firms experience a larger escape competition effect.¹⁷

Differentiating equation (12) with respect to the gap between the profit of a neck-and-neck and laggard bank ($\lambda = \pi_0 - \pi_{-1}$), shows how the Schumpeterian effect is affected by this gap in profits:

$$\frac{\partial^2 n_{-1}}{\partial \pi_0 \partial \lambda} = -\frac{(h + 2n_0) \frac{\partial n_0}{\partial \pi_0} + 1}{((h + n_0)^2 + 2\lambda + n_0^2)^{3/2}} > 0. \quad (14)$$

The Schumpeterian effect is larger if the incremental profits (λ) from innovation of a laggard firm are higher. Hence, laggard firms with scale economies are more likely to innovate, for a given level of competition. Scale economies affect the incremental profit $\lambda = \pi_0 - \pi_{-1}$ since only laggards are subject to the Schumpeterian effect. Post-innovation rents of laggards π_0 with scale diseconomies may be higher if these large firms are more likely to collude.¹⁸ The initial profits of laggards π_{-1} with scale diseconomies may be lower compared to firms on the MES, since scale diseconomies may suppress the profits that can be

¹⁶Although we discuss the possible links between scale economies and collusion in this paper, competition is not endogenously determined in this paper and Aghion et al. (2005b).

¹⁷The escape competition effect is only smaller if firms with scale diseconomies are more likely to behave competitively (low π_0) and if this competitive behavior results in high incremental profits χ from innovation.

¹⁸However, the reverse is also possible, since the effect of scale diseconomies on collusion is ambiguous.

earned. Therefore, laggard firms with scale diseconomies that are more likely to collude after they innovate and experience suppressed current profits have higher incremental profits (λ) from innovation and a larger Schumpeterian effect.¹⁹

In sum, the magnitude of the escape competition and Schumpeterian effect depends on the current level of the incremental profits, which in turn are affected by the scale (dis)economies of a bank. The influence of scale economies on incremental profits is ambiguous and hence an empirical issue. The slope of the inverted-U relationship also depends on the magnitudes of the escape competition and Schumpeterian effect. If banks indeed become 'too big to innovate', larger escape competition and Schumpeterian effects may lead to a steeper inverted-U relationship between competition and innovation.

3. Data and Methodology

This section provides a short description of the data and presents innovation, scale economies and competition measures, as well as our set of control variables and our estimation strategy.

3.1. Data

Our sample consists of a large number of individual banks over the period 1984-2004 in the United States. On average, around 10,500 banks per year are included in the dataset. Information is gathered from the Call reports for Income and Condition provided by the Federal Reserve System. The Call Reports are quarterly income statement and balance sheet data that all federally insured banks are required to submit to the Federal Deposit Insurance Corporation (FDIC). The data cover all banks regulated by the Federal Reserve System, the Federal Deposit and Insurance Corporation and the Comptroller of the Currency. For the purpose of this study, we include only independent banks, in order to avoid measurement problems, in particular when measuring competition.²⁰ The Call Reports include complete balance sheet and income statement data. All data are expressed in 1984 U.S. dollars.

3.2. Measuring Innovation

In Aghion et al. (2001) and Aghion et al. (2005b), innovations result in changes in the unit labor requirement, as shown in Figure 1b in the previous section. In the empirical literature, relating shifts in a cost function, i.e., technical change, to (process) innovation is not new (Subramanian and Nilakanta, 1996; Ruttan, 1997; Agrell et al., 2002; Bleaney and Wakelin, 2002). Our approach to measuring innovation falls into this tradition, and closely aligns with the theoretical concept of the technology gap as stipulated in Aghion et al. (2001) and Aghion et al. (2005b).

The measurement of technical change has gone through a number of developments. For a long time, the econometric approach, led by Tinbergen (1942), consisted of including a time trend when estimating a cost (or production) function. Likewise, using index number theory, Solow (1957) identified neutral technical change, with constant marginal rates of substitutions. Put differently, in line with Tinbergen (1942) and Solow (1957), a change in the cost curve in Figure 1b would be a parallel shift, leaving the (other) parameters in the cost function unaffected.

For the index numbers approach, Diewert (1976) and others that followed, added flexibility to the measurement of technical change, relaxing the assumption that the latter was constant. For the econometric approach, Baltagi and Griffin (1988), by introducing a general index of technical change, relax the assumption that technical change is constant in time. In addition, building on advances by Gollop and Jorgenson (1980) and others, they allow for biased technical change, as marginal rates of substitution are allowed to vary over time. The result is depicted in Figure 1b, where a shift of the cost curve from $t = 1$ to $t = 2$ is not (necessarily) parallel, and can, for example, reflect a skill bias.²¹

¹⁹The Schumpeterian competition effect is only smaller if laggards with scale diseconomies are more likely to behave competitively and experience increases in their average costs (low π_0). These laggards have low incremental profits and are relatively less affected by an increase in competition.

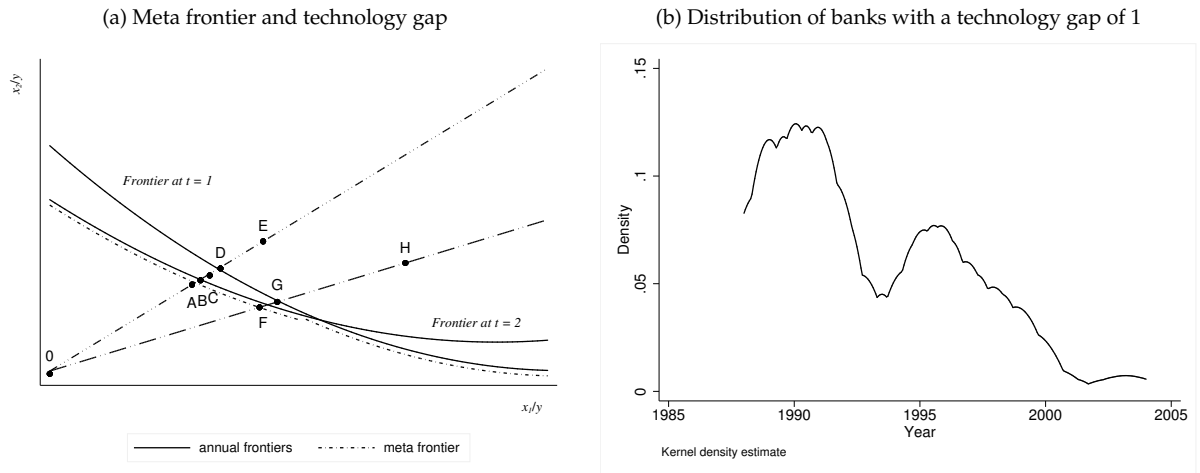
²⁰We selected independent banks using Call Report items RSSD9397, RSSD9001 and RSSD9365.

²¹The relationship between biased technical change and innovation is explained in Acemoglu (2002).

The advances described so far, consist of adding flexibility to the aggregate cost function, which is thereby allowed to evolve over time. Since the cost function describes the process whereby firms are assumed to minimize costs while producing output, the set of estimated parameters reflects the state of technology. What separates technical change from other means of minimizing costs (such as adjusting the input mix or reducing waste), is the fact that whereas the latter measures use the currently implemented technology, technical change consists of the invention or adoption of a new technology. In an attempt to reconcile this view of technical change with the notion of estimating cost functions, early work by Hayami and Ruttan (1970), Mundlak and Hellinghausen (1982) and Lau and Yotopoulos (1989) has focused on the notion of a *meta frontier*. The latter encompasses the set of available technologies, across firms and/or across time. In this view, technical change consists of the adoption of a new technology, and is measured against the benchmark meta frontier, which combines all available technologies.

Figure 2a is used to explain the concept of the meta frontier, with a simple example based on cost minimization with two inputs (x_1, x_2) and a single output (y) and for two firms I and II. In this example, there are two annual frontiers, for $t = 1$ and time $t = 2$. Each frontier represents the minimum cost curve for a certain level of output, based on the available technology in period t . The cost efficiency of firm I, located at point E at time $t = 1$ is OD/OE . If firm I is at point C at $t = 2$, its efficiency is OB/OC . Figure 2a also shows that a second firm, II, is located at point H and faces a cost efficiency of OG/OH at time $t = 1$. The dashed line that envelops the annual frontier in Figure 2a represents the minimum cost frontier over the whole period, or meta frontier. Innovation results in a lower gap between the annual minimum cost frontier and the meta frontier. Innovation is then reflected by changes in the technology gap, which measures the difference between currently available technology and optimal, available technology over the whole period with values between zero and one (i.e., the firm is on the meta frontier).²² At $t = 1$ the firm faces a technology gap of OA/OD , which narrows to OA/OB at $t = 2$ as the firm improves its technology set. While firm I faces a technology gap of OA/OD in period $t = 1$, the technology gap of firm II is smaller (OF/OG).

Figure 2: Technolog gaps in U.S. banking



We follow recent work by Battese et al. (2004), O'Donnell et al. (2008) and Bos and Schmiedel (2007), and obtain technology gaps by, first, employing Stochastic Frontier Analysis (SFA) to estimate the minimum cost frontier available in each year, and second, enveloping the resulting annual cost frontiers to obtain a

²²The notion of technology gaps has been first used by Krugman (1979) and proxied in the literature by total factor productivity (TFP) differentials (Griffith et al., 2004).

meta frontier by following early works of Hayami and Ruttan (1970), Mundlak and Hellinghausen (1982) and Lau and Yotopoulos (1989).²³

The first step consists of estimating an annual translog cost frontiers using stochastic frontier analysis.²⁴

$$TC_{it} = f^*(w_{it}, y_{it}, z_{it})e^{v_{it}+u_{it}}, \quad (15)$$

where w represents the vector of input prices, y the output vector, z a vector of control variables, v the random noise component which is assumed to be i.i.d. $N(0, \sigma_v)$, and u the inefficiency term which is assumed to be i.i.d. $N|(\mu, \sigma_u)|$. We use stochastic frontier analysis, since this allows for the presence of inefficiency, which is completely ignored by the conventional measures of productivity (e.g., TFP) that conflate technical change with efficiency change (Bos et al., 2009).

We assume that banks minimize their total costs and operate in perfectly competitive input markets. The activities of the banks are specified according to the so-called intermediation approach (Freixas and Rochet, 1997). Therefore, the output vector y consists of loans, investments, and off-balance sheet items.²⁵ Input prices, w , include the price of fixed assets, the price of labor, and the price of borrowed funds.²⁶ The equity ratio is included as a control variable z to account for different risk profiles of banks (Hughes and Mester, 1993). The composed error in equation (15) is $\varepsilon_{it} = v_{it} + u_{it}$. Firm-specific inefficiency estimates $u_{i,t}$ are obtained by using the expected value of u_{it} conditional on the total error ε_{it} (i.e., $E(u_{it}|\varepsilon_{it})$). Cost efficiency score estimates are obtained as follows:

$$CE_{it} = [\exp(-\hat{u}_{it})], \quad (16)$$

where CE equals 1 for banks that operate on the annual frontier (no inefficiency). Banks that are subject to inefficiencies are operating above the annual cost frontier and have cost efficiency scores less than 1.

Our second step consists of estimating the meta frontier as the envelope around these annual cost frontiers. We use the parameter estimates for the annual cost frontiers and estimate the distance between the annual frontier (f^*) and meta frontier (f_{meta}):

$$Min.Distance = \sum_{t=1}^T \sum_{i=1}^N |ln f^*(w_{it}, y_{it}, z_{it}) - ln f_{meta}(w_{it}, y_{it}, z_{it})| \text{ s.t. } ln f_{meta}(\cdot) \leq ln f^*(\cdot). \quad (17)$$

In the constrained minimization problem above, the absolute distance between the annual cost frontier and the meta frontier is minimized subject to the constraint that the total costs from the annual frontier is equal to or larger than the total costs from the meta frontier. As a result, the technology gap is defined as:

$$GAP_{it} = \frac{f_{meta}(w_{it}, y_{it}, z_{it})}{f^*(w_{it}, y_{it}, z_{it})}. \quad (18)$$

Innovations by firms may lead to improvements in their technology set and therefore a smaller gap between the current technology set and the (potentially available) best technology set, namely the meta frontier. The result is an increase in the GAP_{it} , which is bounded between 0 and 1, where the latter is reached when firms operate on the meta frontier.

The mean of the technology gap in our data is 0.989 (see Table 1 on page 12). Figure 2b shows the distribution of banks over the period 1984-2004 with a technology gap equal to 1. This means that these banks are using the best of the available technologies over the period and operate on the meta frontier. The average bank size was much smaller in the 1980s and early 1990s. This may be one explanation why, in

²³Kumbhakar and Lovell (2000) provide an elaborate discussion of the development and application of SFA to efficiency measurement.

²⁴Homogeneity of degree one in input prices and symmetry are imposed.

²⁵The output quantities are year-end stocks.

²⁶The price of fixed assets is calculated by taking the depreciation over fixed assets, the price of labor is obtained by dividing the personnel expenses by the number of fte-employees and the price of borrowed funds equals the interest expense divided by the total borrowed funds.

this period, banks had an easier time reaching the meta frontier, given the amount of inputs and outputs involved in the production process. As banks increased in size, and presumably in complexity, bridging the technology gap can become more challenging. Another explanation for the same trend, however, may be a possible decline in competition during the sample period. We therefore now turn to our approach to measuring competition.

3.3. Measuring Competition

We measure competition in the banking sector by using one minus the price cost margin (viz., the Lerner index, or markup) as in Aghion et al. (2005b):

$$C_{it} = 1 - \left(\frac{\Pi_{it} + F_{it}}{R_{it}} \right), \quad (19)$$

where Π_{it} is the profit of a bank, F_{it} represents the fixed costs and R_{it} are the total sales of each bank. The price cost margin of a bank is obtained by dividing the net income after taxes and extraordinary items plus expenses of premises and fixed assets by total non-interest income plus total interest income. A firm-specific measure of competition is preferred instead of using a measure based on a certain geographical market as some banks compete mainly at the local level while other banks compete mainly at the national or international level. Hence, we assume that all changes in competition are reflected in the price cost margins of banks despite of the scope of the geographical market in which banks are competing. After the exclusion of outliers, the price cost margin and the competition measure range between -1 and 1, and 0 and 2, respectively.²⁷

3.4. Measuring Scale Economies

We employ two measures for scale economies. The first measure is a firm size measure based on total assets.²⁸ There should be a direct correlation between scale economies and firm size as firms that are below the MES are usually the (relatively) smaller firms in an industry. This measure, however, has two main drawbacks. First, the firm size variable may capture other effects than scale economies in production. Second, while a certain firm size may be characterizing the MES in a given year, the same firm size may indicate scale economies in other years (see Figure 1).

An alternative measure is based on the elasticity of total costs with respect to the outputs. By using SFA, we estimate cost functions and calculate the elasticity as follows:²⁹

$$Scale_{it} = \sum_{k=1}^3 \frac{\partial \ln TC_{it}}{\partial \ln y_{kit}}, \quad (20)$$

where k indicates the three different outputs used in this paper, namely loans, investments and off-balance sheet items.

The SFA scale economies are calculated for a given output bundle keeping the output mix constant.³⁰ If the scale economies variable is equal to 1, the production is subject to constant returns to scale. If the value is lower than 1, it indicates scale economies. Values larger than 1 indicate scale diseconomies. A drawback of this measure is that it is a generated regressor that is constructed from a similar underlying procedure that is used to obtain the technology gap.

²⁷ Scatterplots of the technology gap and the price cost margin were used to check for outliers. In total, 1324 observations (less than 1% of the original sample) were excluded. A range of the price cost margin between -1 and 1 was considered to be reasonable. Some authors choose to remove negative price cost margins, but this approach creates a bias in the results as only firms with positive price cost margins are considered. The dataset contains 14,073 observations with negative price cost margins.

²⁸ The hypothesis that large firms are more than proportionally innovative compared to smaller firms is associated with the work of Schumpeter. There are many channels through which larger firms may have innovation advantages over smaller firms. For example, larger firms may have an advantage because they have more researchers which may lead to more productive interaction in this large research group. It is also possible that larger firms are more able to diversify risky innovation projects.

²⁹ For example, see Hunter and Timme (1991), Bernstein (1996) and Altunbas et al. (2001) for applications of this scale economies measure in the banking sector.

³⁰ As opposed to scale biased technical change, where technical change may result in a change of the cost-minimizing size of the firm (Hunter and Timme, 1991).

3.5. Control variables

We include two control variables in our analysis. The equity ratio is included as a control variable to account for the relationship between the risk of a firm and innovation. Aghion et al. (2005b) argue that more debt pressure has a positive effect on the innovation incentives of firms. This positive effect is interpreted as an attempt of firms to escape from their existing debt pressure through innovations. Furthermore, the average wage per fte-employee (salary expenses divided by the number of fte-employees) is also included in our analysis as a proxy for human capital, as high quality workers may foster innovations (Funke and Strulik, 2000).³¹

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Technology gap	0.989	0.029	1.07e-08	1.000
Price cost margin	0.179	0.090	-0.993	0.964
Total assets per millions of USD	458.740	7416.978	1.067	967,365
Scale economies (from SFA)	1.099	0.071	0.726	1.737
Risk (Equity/Total Assets)	0.096	0.034	7.36e-05	0.998
Salary expenses per fte in thousands of USD	35.143	12.756	0.048	537.160

151,476 observations. The descriptive statistics are based on the sample of the preferred specifications in Table 2.

Table 1 provides the descriptive statistics of the variables employed in our analysis.³² We observe a large spread in the price cost margin. Also, both scale economies (values smaller than unity) and scale diseconomies exist in our sample.

3.6. Empirical Specification

Our empirical specification is based on Aghion et al. (2005b), but extended to account for the impact of scale (dis)economies:

$$GAP_{it} = \beta_1 C_{it} + \beta_2 C_{it}^2 + \beta_3 S_{it} + \beta_4 S_{it} C_{it} + \beta_5 S_{it} C_{it}^2 + \gamma' \mathbf{Z}_{it} + a_i + \varepsilon_{it}, \quad (21)$$

where GAP is the technology gap, C competition, S total assets or the SFA scale economies variable, γ' $1 \times n$ parameter vector, and \mathbf{Z} an $n \times 1$ vector of control variables. A squared term of the competition variable, C^2 , is included to account for the possible inverted-U relationship between competition and innovation according to Aghion et al. (2005). The interaction terms with the scale economies measure, SC and SC^2 , are included to allow the inverted-U relationship to be different for each firm due to differences in scale economies.

The conditions in equation (13) and (14) show that the magnitude of the escape competition effect and Schumpeterian effect depends on the incremental profits that a firm can earn by innovating. Whether a firm experiences scale economies or scale diseconomies may affect this incremental profit and therefore the magnitude of the escape competition effect, Schumpeterian effect and the steepness of the inverted-U relationship. Taking first-differences of equation (21) to eliminate the unobserved heterogeneity a_i gives:

$$\Delta GAP_{it} = \beta_1 \Delta C_{it} + \beta_2 \Delta C_{it}^2 + \beta_3 \Delta S_{it} + \beta_4 \Delta(S_{it} C_{it}) + \beta_5 \Delta(S_{it} C_{it}^2) + \gamma' \Delta \mathbf{Z}_{it} + \Delta \varepsilon_{it}. \quad (22)$$

We also estimate equation (22) replacing the continuous scale economies measure with a dummy variable that indicates above average scale economies (1) or below average scale economies (0).

³¹We assume that the wages of high quality workers are higher.

³²The total number of observations is approximately 220,000 with on average 10,500 banks each year. Eventually, we have 151,476 observations in the preferred specification due to missing values of several variables, the exclusion of outliers, applying first-differences, and using lags of the endogenous regressors as instruments.

While competition and scale economies affect innovation, innovation may also affect competition and scale economies. For example, firms may become more dominant in a market after surpassing other competitors due to successful innovations.³³ Innovations may also increase the MES. Therefore, lags of these endogenous variables are used as instruments. The lag structure of the instruments depends on the order of autocorrelation in the residuals.³⁴ If the residual in equation (21) is not autocorrelated, lags of period $t-2$ can be used as instruments for the endogenous regressors in equation (22). If there is first-order autocorrelation, lags from period $t-3$ and deeper can be used. Furthermore, we use the two-step generalized method of moments estimator (GMM). The GMM has some efficiency gains compared to the traditional instrumental variable (IV) or two-stage least square (2SLS) estimators. For example, the two-step GMM estimator utilizes an optimal weighting matrix that minimizes the asymptotic variance of the estimator. Also, GMM is more efficient than the 2SLS estimator in the presence of heteroskedasticity.

4. Results

In this section, we present our results. First, we investigate the development of the scale economies, average bank size and the average price cost margin over time. Next, we explore whether U.S. banks have become too big to innovate.

4.1. How have scale economies and competition developed in the consolidating U.S. banking market?

The model of Aghion et al. (2001) and Aghion et al. (2005b) analyzes how banks' innovative behavior changes as their competitive position changes. The resulting market dynamic is therefore grounded in firm-level differences. If there is no room to explore scale economies, banks are less able to reap the bonus that awaits them when they innovate. Likewise, if there are no banks operating beyond their MES, there is no such thing as being 'too big to innovate'.

Figure 3: Scale economies, total assets and the price cost margin

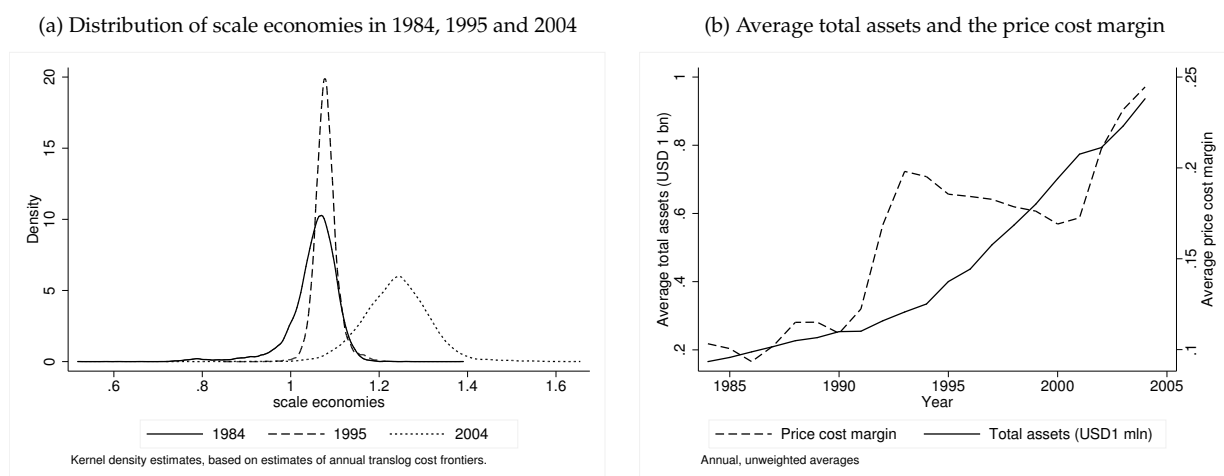


Figure 3a shows how the distribution of scale economies has evolved over our sample period. The figure shows two concurrent developments. First, the number of banks with scale diseconomies has grown over time. Second, as the market consolidated, the distribution of scale economies narrowed mid sample

³³However, Geroski and Pomroy (1990) argue that more innovations may lead to more competition.

³⁴The Arellano-Bond autocorrelation test is based on the examination of residuals in first differences. Testing for first-order serial correlation in levels is based on testing for second-order serial correlation in first differences.

(i.e., in 1995), but widened again towards the end of the sample period. Summing up, Figure 3a reflects a consolidating market, with plenty of differences in the potential penalty (or bonus) for innovators.

The story of a consolidating market is repeated in Figure 3b, which shows the development of average bank size (total assets in \$bn) and the average price cost margin over the sample period. Interestingly, the peak in the price cost margin more or less coincides with the mid sample period, when the market was at its most homogenous in terms of scale economies. As Figure 3b shows, competition has decreased, on average, over the sample period. This finding is consistent with the results of Stiroh and Strahan (2003), who argue that the banking deregulation ignited a reallocation of banking assets from low profit to high profit banks. Meanwhile, the average bank size increased from total assets around 165 million dollars to around 936 million dollars in 2004.

The developments in scale economies and competition, together with the development of the technology gap described in Figure 2b, tell the story of a market with a lot of dynamics, and plenty of potential for banks to become 'too big to innovate'. The latter issue is investigated further in the next subsection.

4.2. Have large US banks become too big to innovate?

In this section, we investigate the influence of scale economies on the competition-innovation relationship. Before we examine whether large US banks have indeed become 'too big to innovate', we need to establish the overall nature of the competition-innovation relationship.

We therefore start with the first set of estimation results in Table 2, where we estimate the basic model specification, including control variables and total assets, but without allowing for a possible effect of the latter on the competition-innovation relationship. The results are shown in columns (i) and (ii), where we report both OLS (in column (i)) and two-step GMM (in column (ii)) estimates.³⁵ As is clear from the significant positive (negative) relationship for the competition measure (squared competition measure), there is indeed an inverted-U competition-innovation relationship: as competition increases, innovation initially rises, until it reaches a peak, after which the Schumpeterian competition effect dominates.³⁶ Interestingly, the optimal price cost margin that enhances innovation is 5.8%. Looking back at Figure 3b, we observe that on average this price cost margin is first reached around 1992, and again around the year 2000. Of course, comparing with Figure 3a, we know that a major difference between these two (sub-)periods lies with the development of scale economies.

These results are in line with Bos et al. (2009), who also report an inverted-U relationship for U.S. banking. In line with Aghion et al. (2005b), we find that banks with a higher equity ratio feel less debt pressure and are as a result less innovative. In our (preferred) GMM specification, a higher average wage has no effect, reflecting the fact that human capital has no considerable effect on banks' (process) innovativeness. And although firm size (S) is statistically significant at the 5% level in column (i), there is no evidence of a significant relationship between firm size and the technology gap once we treat the competition variables as endogenous regressors (column (ii)).³⁷

Next, we proceed by investigating whether large U.S. banks have become to 'too big to innovate'. To this purpose, we allow interaction between scale economies and competition, so we can measure the effect of scale economies on the competition-innovation relationship. To accurately study this effect, we include scale economies in three different ways, presented in columns (iii), (iv) and (v) of Table 2. Each approach has its own advantages. In the first approach, presented in column (iii), scale is accounted for by banks' total assets. The advantages of this scale measure are that it is continuous, and (presumably) precisely measurable.³⁸ Therefore, we shall use this estimation in comparison with the earlier described results, in

³⁵For the GMM estimation, we use instruments from periods $t - 3$ and $t - 4$, since there is evidence of first-order autocorrelation in the residuals in levels. The instruments are relevant and valid according to first-stage F-tests and the Hansen test, respectively. The instrument relevance test is based on the joint significance of the instruments, with a critical value for the F-statistic of 10 applied as an often used rule of thumb. The F-statistics for the regressions with the competition variable and its squared term as a dependent variable are 413.84 and 251.56, respectively.

³⁶Both competition variables are individually and jointly significant at the 1% level.

³⁷There is also no significant effect of firm size on the technology gap if we treat the firm size variable as endogenous with lags from period $t-3$ and $t-4$ as instruments. In the remaining part of the paper we do not examine the marginal effect of firm size on the technology gap and focus only on the (conditional) marginal effect of competition on the technology gap.

³⁸A possible disadvantage is that other things besides scale economies may affect the competition-innovation relationship.

order to assess the effect of scale on the optimal price cost margin. In the second approach, presented in column (iv), we replace the scale measure with a dummy, which takes on the value 1 (0) when bank size is above (below) the industry average.³⁹ The advantage of this scale measure is that it allows us to easily compare the effect of operating below and above average total assets on the shape of the inverted-U relationship. Our third and final approach consists of measuring scale with scale economies estimates, as described in Table 1. Based on these estimates, we define a dummy that takes on a value of 1 (0) if a bank has scale economies above (below) the sample average.⁴⁰ The advantage of this measure is that it allows us to more accurately differentiate between banks operating above and below average scale economies.⁴¹ Comparing coefficients in columns (iii), (iv) and (v) reveals that results in all cases are qualitatively similar. The inverted-U relationship and the joint effect of the interaction terms are significant in all three cases.⁴²

Table 2: Estimation results: inverted-U

Specification	(i) OLS	(ii) 2-step GMM	(iii) 2-step GMM	(iv) 2-step GMM	(v) 2-step GMM
ΔC_{it}	0.025*** (0.009)	1.474*** (0.106)	1.468*** (0.105)	0.863** (0.348)	0.303 (0.847)
ΔC_{it}^2	-0.022*** (0.005)	-0.783*** (0.062)	-0.778*** (0.062)	-0.458** (0.183)	-0.068 (0.472)
ΔS_{it}	-0.0001** (0.00006)	-0.00009 (0.00006)	-0.006 (0.005)	-0.281 (0.256)	-1.663*** (0.522)
$\Delta S_{it} * C_{it}$			0.018 (0.012)	0.556 (0.500)	4.331*** (1.240)
$\Delta S_{it} * C_{it}^2$			-0.013 (0.009)	-0.360 (0.275)	-2.720*** (0.726)
ΔR_{it}	-0.162*** (0.015)	-0.124*** (0.037)	-0.123*** (0.037)	-0.107*** (0.032)	-0.749*** (0.131)
ΔW_{it}	-0.0001** (0.00004)	-0.00006 (0.00006)	-0.00006 (0.00006)	0.00009 (0.00006)	-0.00006 (0.00009)
Observations	198,785	151,476	151,476	151,476	150,537
AR(1)		0.000	0.000	0.000	0.000
AR(2)		0.000	0.000	0.000	0.000
AR(3)		0.795	0.770	0.4421	0.8615
Hansen J statistic		0.797 (0.671)	3.609 (0.607)	14.417 (0.0132)	8.671 (0.013)

The dependent variable is innovation, proxied by the technology gap, GAP . C is competition, S is scale economies proxied by total assets (or estimated scale economies, in specification (v)), R is the equity ratio, and W is the average wage per fte-employee. Standard errors (between parentheses) are robust against heteroskedasticity and serial correlation. Asterisks indicate significance at the following levels: * – 0.10, ** – 0.05, and *** – 0.01. The p-values are reported for the Arellano-Bond serial correlation test. The chi-squared statistic and p-value (between brackets) are reported for the Hansen test.

We start by evaluating the effect of scale on the optimal price cost margin. To do so, we compare the results in column (ii) with those in column (iii).⁴³ Our findings suggest that the inverted-U relationship between competition and innovation is bank-specific, and depends on the size of the bank and thus

³⁹A possible disadvantage of this measure is the (lack of) accuracy with which we measure MES. We have also experimented with other cut-off points, including those based on our estimated scale economies (from Table 1). The results are robust.

⁴⁰We also estimated column (v) using scale economies of unity as a cut-off point. Results are qualitatively similar.

⁴¹A disadvantage is of course the fact that this is a generated regressor, which requires us to be careful when discussing its significance.

⁴²Since the main interest of the paper is to examine whether the marginal effect of competition on innovation depends on the scale economies of firms, we follow Brambor et al. (2006) and use the standard deviation of the marginal effect to examine the significance of the conditional marginal effect as specified in column (iii). The conditional marginal effects of competition on the technology gap evaluated at the mean, median, 10th, 90th and 99th percentile are significant at the 1% level. For columns (iv) and (v), the coefficients of the interaction terms and the group dummy are jointly significant at the 1% level, but not individually. Furthermore, in column (v), the coefficients on competition and competition squared are jointly significant at the 1% level, but not individually.

⁴³The instruments used in estimating the specification in column (iii) are jointly significant at the 1% level in the first stage re-

whether the bank experiences scale economies or scale diseconomies. The average *optimal* price cost margin for banks with total assets more than \$654,000,000 (95th percentile) is around 7.3%, compared to the 5.8% found earlier. However, on average the *actual* price cost margin for these banks 18.8%.⁴⁴ Interestingly, these high rents cannot be explained by cost advantages, as these banks operate beyond the MES. The coefficients on the interaction terms indicate that the innovation behavior of larger banks is more responsive to changes in competition. Hence, the innovation incentives of large banks are diminishing if these banks continue to earn higher rents in the future.

In column (iv), we examine this interaction effect by comparing two groups, namely large and small banks.⁴⁵ Since the scale measure in the specification in column (iv) is a dummy variable, the coefficients on the interaction terms clearly capture the difference in the slopes of the inverted-U for banks operating below and above average scale economies (measured as total assets). The result is depicted in Figure 4. The optimal price cost margin for both groups is slightly positively. For the most part, large banks manage to have better technology sets. However, as competition decreases, and we move from the middle to the left in Figure 4, the technology gap drops at a much quicker pace for these large banks. Put differently, if consolidation proceeds, and competition decreases further, overall innovation (reflected by changes in the technology gap) by U.S. banks is expected to drop sharply, as these large banks dominate the market. Put simply, these large banks have indeed become 'too big to innovate'. Evaluated at the average price cost margin of 17.9%, the marginal effect of competition on the technology gap for banks with below and above average total assets is 11 and 7 percentage points, respectively. Hence, an increase in competition leads to relatively more innovation by smaller banks that operate near the average price cost margin.⁴⁶

Column (v) shows the results when we employ a dummy (S) based on scale economies estimated using annual cost frontiers.⁴⁷ The dummy variable separates groups with below and above average scale diseconomies. The results based on this alternative measure of scale economies also imply that the innovation behavior of banks with larger scale diseconomies is more responsive to changes in competition. Further decreases in competition lead to a relatively large drop in innovations by large banks. By evaluating the marginal effect of competition on technology gaps for both groups at the average price cost margin of 17.9%, we conclude that banks with below average scale diseconomies benefit more from an increase in competition. If the price cost margin increases by 1 percentage point, the technology gap increases by approximately 19.2 percentage points for banks with less scale diseconomies, while banks with larger scale diseconomies experience only an increase of 5.6 percentage points.⁴⁸

Summing up, we have shown that large banks earn considerable rents, that they have become 'too

gressions, with the competition variable, competition squared, firm size, the interaction between firm size and competition, and the interaction between firm size and competition squared as dependent variables. The F-values are 167.87, 102.35, 39.51, 40.55 and 23.32, respectively. Instruments from period $t - 3$ and $t - 4$ are used, since there is evidence of first-order autocorrelation in the residuals in levels. The instruments are relevant and valid according to first-stage F-tests and the Hansen test, respectively.

⁴⁴Furthermore, the average annual *change* in the price cost margin is positive (0.7%) for these banks. Also interesting is the fact that 95% of the observations from the preferred specification in column (iii) in Table 2 have price cost margins higher than the optimal price cost margin associated with each observation. This means that banks are operating mostly on the left of the optimal point that enhances innovation in the inverted-U relationship between competition and innovation. However, we also allowed for a 5% deviation of the optimal price cost margin, since none of the banks operate exactly on the optimal price cost margin that enhances innovation. In this case, 88.7% of the observations have price cost margins below the optimal price cost margin minus the 5% deviation from this optimal point. Only 8.1% of the observations deviated less than 5% from the optimal price cost margin.

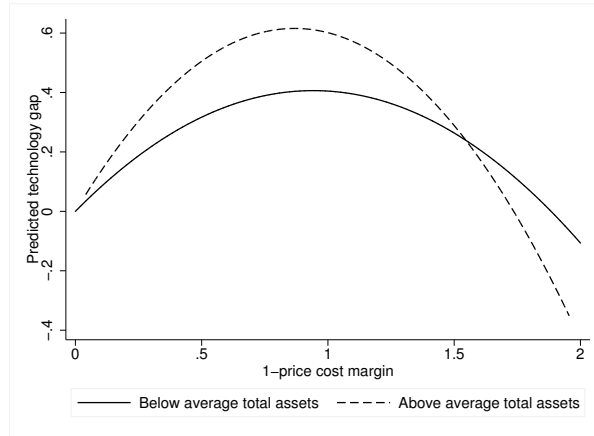
⁴⁵For the specification in column (iv), the Hansen test indicates that the instrument set including lags from period $t-3$ and $t-4$ are valid based on a 1% significance level (which we apply considering the size of our dataset).

⁴⁶The optimal price cost margin for banks with below and above average total assets is 5.8% and 13.2%, respectively. Smaller banks with a price cost margin near the average are operating relatively far away from the optimal point. Hence, the escape competition effect for this group is larger. We also evaluated the marginal effect by using one standard deviation below and above the average price cost margin. In both cases, the effect of competition on the technology gap is stronger for the larger banks. This indicates that these banks are more responsive to changes in competition.

⁴⁷Lags from period $t-3$ are used as instruments for all endogenous regressors due to evidence of serial correlation in the residuals. For the dummy variable we use lags of the continuous scale economies variable as instruments. Lags from period $t-4$ are only used for the competition variable and the continuous scale economies variable. The inclusion of lags from period $t-4$ for the squared terms and interaction terms leads to a rejection of the null hypothesis that the instruments are valid (Hansen test).

⁴⁸We also evaluated the marginal effect by using one standard deviation below and above the average price cost margin. The effect

Figure 4: The competition-innovation relationship



big to innovate', and that the effect on innovation is sizeable. Added to the ongoing consolidation in U.S. banking, these results suggest that policies aimed at increasing competition may have an important positive externality: in addition to the usual downward pressure on prices, increased competition may, ironically, result in further cost reductions, as large banks in particular try to escape competition by innovating.

5. Conclusion

This paper has examined the effect of scale (dis)economies on the competition-innovation relationship in U.S. banking. Theoretical endogenous growth models have ignored this effect, as they rely on the premise that unit costs are independent from output levels. Such models are less appropriate for investigating the effect of competition on innovation in sectors where average costs are not constant.

We have extended the theoretical model of Aghion and Griffith (2005) to allow for a U-shaped average cost curve where firms may operate below, on or beyond the MES. The latter constitutes a novelty of this paper as it allows us to derive conditions under which the magnitude of the Schumpeterian effect and escape competition effect differs between firms. Firms that operate below the MES have a higher bonus when they innovate since they experience more potential for growth. The (process) innovation lowers their average costs, and thereby increases the expected rents from innovating. Firms that operate beyond the MES have less growth potential since firm growth may increase their average costs.

In addition we have introduced a novel way to measure process innovation in banking. The measure of innovation that we utilize focuses on banks' ability to minimize costs through innovations. Innovations improve the technology sets of banks and narrow the technological distance between the technology applied in a bank and the best (potential) available technology. Relying on recent contributions to the estimation of meta cost frontiers, we measure these technology gaps.

Subsequently, we have tested the theoretical implications of our model on a rich data set of U.S. banks. Our main aim was to find whether large U.S. banks have become 'too big to innovate'. We find that most banks in the U.S. start to operate beyond the Minimum Efficient Scale and experience scale diseconomies as the sector consolidates and average bank sizes increase. The upward trend in the average price cost margins during the same period implies that the degree of competition in the banking sector has declined. Our results provide support of an inverted-U relationship between competition and innovation in U.S. banking. This finding is robust over several different model specifications and consistent with the theoretical and empirical work of Aghion et al. (2005b) and Bos et al. (2009).

of competition on the technology gap is stronger for banks with larger scale diseconomies in both cases. This indicates that these banks are more responsive to changes in competition.

Further analysis has revealed the effect of scale (dis)economies on the nature of the competition-innovation relationship in U.S. banking. Large banks are shown to earn considerable rents. Important, the inverted-U relationship between competition and innovation becomes steeper as bank size increases. Our findings have important implications for competition policy. As banks, on average, are becoming larger over time, the increased responsiveness in terms of innovation should be taken into account when implementing competition policies. Any further decreases in competition will prove to be highly detrimental to innovation, due to the more than proportional reduction in innovation by large banks that have become 'too big to innovate'. In contrast, the added bonus of any policy that effectively stimulates competition is a boost in innovation, due to its effect on large banks.

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